

Population synthesis of DA white dwarfs: constraints on soft X-ray spectra evolution

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Abstract. Extending the population synthesis method to isolated young cooling white dwarfs we are able to confront our model assumptions with observations made in ROSAT All-Sky Survey [1]. This allows us to check model parameters such as evolution of spectra and separation of heavy elements in DA WD envelopes. It seems like X-ray spectrum temperature of these objects is given by the formula [2] $T_{\text{X-ray}} = \min(T_{\text{eff}}, T_{\text{max}})$. We have obtained DA WD's birth rate and upper limit of the X-ray spectrum temperature: DA birth rate = $0.61 \times 10^{-12} \text{ pc}^{-3} \text{ yr}^{-1}$, $T_{\text{max}} = 4.1 \times 10^4 \text{ K}$. These values are in good correspondence with values obtained by [3, 2]. From this fact we also conclude that our population synthesis method is applicable to the population of close-by isolated cooling white dwarfs as well as to the population of the isolated cooling neutron stars.

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POPULATION SYNTHESIS OF ISOLATED COMPACT OBJECTS

Population synthesis is a powerful tool in astrophysics [4]. For example, it was successfully applied to the population of close-by cooling isolated neutron stars (see [5] and references therein). The basics of the model are the following. After initial distributions and evolutionary laws for the population under study are specified, a Monte-Carlo calculations of the evolution are made to produce an artificial population of sources. Then, some properties of this population are confronted with the available observational data. Typically, if one (or even several) ingredients are not well known, then comparison with observations can result in important constraints of these poorly defined parameters.

In the case of close-by cooling isolated neutron stars the ingredients include: initial spatial distribution, birth rate, mass spectrum, initial velocity distribution, Galactic potential, cooling history (for a given mass), interstellar absorption, detector properties. The main observational data on close-by NSs useful for population synthesis studies (a uniform set of data) is due to the ROSAT All-Sky Survey. In our previous studies we mainly compared the observed and simulated $\text{Log } N - \text{Log } S$ distributions, where S is a count rate for a given detector and N is a number of sources with count rate larger than a given value ($N(> S)$). Among the ingredients cooling curves are the most uncertain. So, the population synthesis can be used as a test for the models of thermal history of neutron stars [6].

As the population synthesis of close-by cooling isolated neutron stars is a well-established field,¹ we want to expand this approach to study a similar class of sources – close-by cooling isolated white dwarfs (WDs).

INGREDIENTS FOR WD POPULATION SYNTHESIS

Here we present results only for DA WDs, as mostly sources of this type are X-ray bright. The main ingredients of our populations synthesis model are the following:

Spatial distribution and birth rate: We use two different spatial distributions:

1. double-exponential disc: $n_0 \sim \exp(-|z|/z_{\text{scale}})\exp(-R/R_{\text{scale}})$, where R and z are cylindrical coordinates with the origin at the Galactic center, $z_{\text{scale}} = 250$ pc, $R_{\text{scale}} = 3000$ pc;
2. spatial distribution from [7] (one with $t = 7 - 10$ Gyr): $\rho_0/d_0 \times \{\exp(-(0.5^2 + a^2/h_{R+}^2)^{1/2}) - \exp(-(0.5^2 + a^2/h_{R-}^2)^{1/2})\}$, where $a^2 = R^2 + \frac{z^2}{\varepsilon^2}$, R and z are cylindrical coordinates with the origin at the Galactic center, ε is ellipsity of the distribution equals to 0.0791 in our case, $h_{R+} = 2530$ pc, $h_{R-} = 1320$ pc;

As a starting point for fitting the birth rate of DA WDs we take the standard value $10^{-12} \text{ pc}^{-3} \text{ yr}^{-1}$, DA WDs form $\approx 60\%$ of the whole population [3].

Mass distribution: The mass distribution is very important as the cooling history of a WD depends on its mass. A mass also influences the chemical composition of a white dwarf and its spectrum. Birth rates of WDs with different masses are significantly different.

We take the mass distribution from [8], $M_{\text{mean}} = 0.6 M_{\odot}$. It gives us a good first-order approximation. For a more detailed study we plan to use a spatially dependent mass distribution.

Cooling curves: For white dwarfs cooling curves are known much more precisely than for neutron stars. Here we do not put constraints on thermal history of WDs. We use cooling curves of WDs computed with the code STELLA described in [9].

White dwarfs X-ray spectra: As it appeared, the most uncertain part of our population synthesis model is related to X-ray spectra of WDs. This is so because even for moderately hot WDs settling of the heavy elements is not possible due to radiative levitation, and heavy elements contribute more to the opacity in the soft X-ray band. According to our present simple model, the population synthesis shows good correspondence with observations if the X-ray spectra temperatures are assumed to follow the formula: $T_{\text{X-ray}} = \min(T_{\text{eff}}, T_{\text{max}})$.

The X-ray spectra used here are computed by the code described in [10].

From the final $\text{Log N} - \text{Log S}$ it is clearly seen, that the spectral evolution is the most important ingredient of our population synthesis study, and confronting the results of calculations with observations one can constrain the spectral evolution.

¹ Interested readers can look at the on-line version of the population synthesis of isolated close-by cooling NSs: <http://www.astro.uni-jena.de/Net-PSICoNS/> (Boldin, Popov, Tetzlaff, in press).

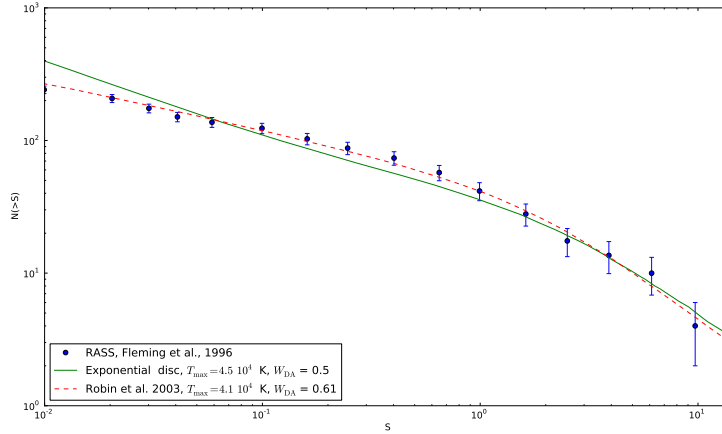


FIGURE 1. Our best-fit Log N – Log S models for different spatial distributions. Solid line is for the double-exponential disc with fitted values $T_{\max} = 45000$ K and DA WD birth rate $= 0.5 \times 10^{-12} \text{ pc}^{-3} \text{ yr}^{-1}$. Dashed line is distribution from [7] with fitted values $T_{\max} = 41000$ K and DA WD birth rate $= 0.61 \times 10^{-12} \text{ pc}^{-3} \text{ yr}^{-1}$, that is overall best-fit model.

Because a spectrum of a WD is flatter in soft X-rays than the blackbody spectrum, it is important to incorporate a good absorption model and the ISM distribution. Our investigation has shown that abundances of elements are also very important, as, e.g. C and O contribute a lot to opacity in the energy range of interest. We used abundances from [11]. According to our results, change in power-law index is caused by change of number density of ISM matter (Local Bubble vs. near-by Galaxy).

RESULTS

In Fig. 1 we show two best-fit (in terms of T_{\max} , W_{DA}) Log N – Log S curves for two different spatial distributions. Our best-fit model is for the spatial distribution from Robin et al. [7] and gives us $T_{\max} = 41000$ K and $W_{\text{DA}} = 61\%$. These values are in surprisingly good correspondence with values obtained independently ([2, 3])

In Fig. 2 we show two age-distance distributions of calculated WDs. Both panels are plotted for the best model with distribution from Robin et al. [7] and $T_{\max} = 4.1 \cdot 10^4$ K (dashed on the Log N – Log S plot). Shaded areas mark the distance range of the Gould Belt ($300 \text{ pc} < D < 500 \text{ pc}$).

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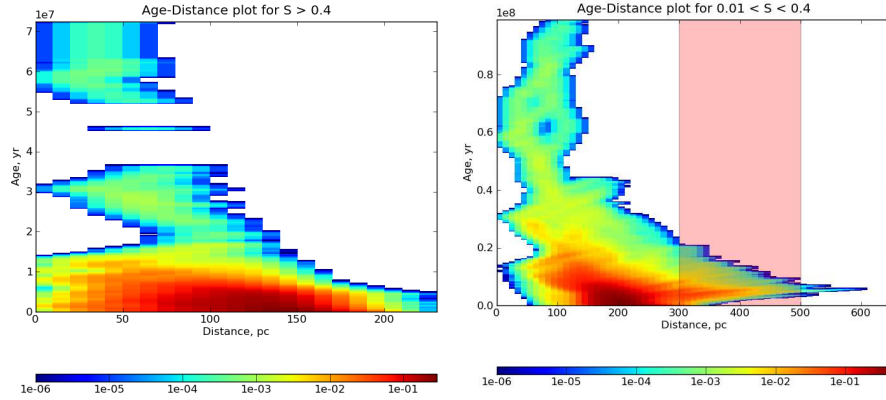


FIGURE 2. *Left:* Age-Distance plot (number density in the plane age-distance of objects with given S) for bright sources ($S > 0.4$ cts/s). *Right:* Age-Distance plot for intermediate bright objects where the model underpredicts the observed numbers ($0.01 < S < 0.4$). The shaded region corresponds to the Gould Belt.

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